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Project Number: 20190124ER
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Report Contributors

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OVERALL ASSESSMENT SUMMARY

This project was successful in addressing key technical issues of the cone-guided electron fast ignition concept for ICF. The development of an e-beam to deliver energy of 10’s of kilojoules to HED targets would be useful for myriad experimental applications relevant to the Laboratory’s mission. For example, ICF ignition and the development of a burning plasma is a high priority for the national high energy density physics effort and this work is aligned with that mission. Moreover, other technologies (e.g., MeV laser radiography) would be advanced by the R&D advancements from this project, so this work has broader implications for other LANL missions.

The two main results of this project were the exploration of a novel plasma absorber concept for mitigating pre-plama cone-filling source degradation and exploration of the vacuum laser absorption process in the relativistic laser-plasma interaction. Efforts in both areas were successful.

The project suffered from COVID logistical challenges, most notably a severe lack of relevant experiments, which led to somewhat lower production than normal for an LDRD ER project (e.g. two publications, few invited talks, no postdocs who stayed on as technical staff). However, the team is to be commended for producing quality scientific results in light of these challenges. For these reasons, we give the project an overall score of Good/Excellent.

CRITERIA ASSESSMENT

Mission Agility: Enable agile responses to national security challenges.

Score: <u>Excellent/Good</u>
How does the project meet the appraisal criteria for Mission Agility?

The research performed here integrated LANL expertise in the areas of rad-hydro modeling, PIC simulation, target fabrication and experimental execution to further the complex technical understanding of laser driven electron acceleration. The project has been successful in addressing key technical issues of the cone-guided electron fast ignition concept. ICF ignition and the development of a burning plasma are high priorities for the national high energy density physics community, with which this work is aligned. Moreover, other technologies (e.g., MeV laser radiography) would be advanced by continued R&D results from this project, so there are further implications for LANL missions should this work continue into the future.

The research team identified some of the basic problems and evaluated different approaches to mitigate problems plaguing efficient laser-driven cone-guided acceleration of electrons. They developed a novel (for fast ignition) plasma absorber concept to obviate pre-plasma degradation of electron beam delivery to the hot spot. Their approach appears promising in simulations and determinative experiments are planned later this fiscal year.

A weakness of the work presented was the limited experimental and calculational evaluation of these concepts and the limited time for feedback between experiments and calculations, thus decreasing the work's overall programmatic impact. This was likely a consequence of COVID and the resulting decrease in available facility time and experimental contingency planning.

Strengths/Weaknesses:

Strengths
- The team is very strong in the modeling area and have novel new scientific predictions.
- This work could enable new experiments in the ICF and HEDP fields.

Weaknesses:
- Improved cross-laboratory efforts are encouraged, especially on the experimental side.
- No new theoretical model was developed to help parameterize the relevant physics at play. For example, understanding issues with Alfven current limit would have been good or a model for the burn through of the pre-pulse foil.
- No experimental time on Omega-EP was obtained during the traditional 3-year ER performance period. More diverse experimental contingency plans are needed requiring management and program involvement. This problem is common across many laser-based LDRD proposal efforts. A cohesive plan with Science Campaign guidance is needed (with a designated LDRD/SC leader advocate/champion).
- Mixing of gold cone material into the hot spot could have been looked at with xRAGE and would have made a nice LANL-centric contribution, especially when manpower efforts needed to shift to more computational efforts when experimental shot requests for Omega EP time were not approved during the first 3 years.

Technical Vitality: Advance the frontiers of science, technology, and engineering.

Score: Excellent
How does the project meet the appraisal criteria for Technical Vitality?

The team used simulations and experiments to explore novel ideas to improve electron source generation with short pulse lasers and conceived of experimental ways to easily test their hypotheses. Using numerical simulations, the team identified the presence of pre-plasma inside the cone of a fast ignition target caused by the pre-pulse/pedestal of the laser pulse that degrades the electron beam generated from the cone. Most importantly, the plasma absorber concept they developed and evaluated through simulation is a novel mitigation scheme for fast ignition, even though burn-through foils or layers exist in other ICF concepts (e.g., the MagLIF window or LEH windows on ICF hohlraums), so the idea isn't wholly novel in this regard. Significant advances were made understanding why previous cone-guided experiments did not work, and their potential solution to obviate these issues will be tested soon (June, 2022).

In the absence of Omega EP experiments, the team also studied the fundamental physics of laser-driven electron beam generation via Vacuum Laser Acceleration (VLA) both experimentally, at Colorado State University (CSU), and numerically. VLA is one of the mechanisms of electron beam generation inside the cone. The team did a good job using LANL's modeling capability to assess some of the pros and cons of this approach which the team published in a high-profile technical journal article in Nature Communications.

Strengths/Weaknesses:
Strengths:
- Nature Communcations publication is laudable.
- The thin foil absorber concept is a simple idea but potentially very impactful across many short pulse applications.
- Burn-through foil evaluated in simulations to help parameterize future experimental target designs.

Weaknesses:
- Hindered by lack of experimental contingencies and lack of awarded experimental time.
- Hindered by COVID19 isolation.
- More representation at (virtual) conferences would have been good.
- The overall results should discuss broader applications of this research.
- Only 2 publications over 3 years.
- Modeling using xRAGE's plasma diffusion model might also have been illuminating.
- It would have been nice to see some 3D calculations of the plasma absorber concept to see to what degree inclusion of the third dimension would affect beam propagation behavior through the absorber plasma.
- It would have been useful had the team presented some more quantitative analysis of the effects on laser propagation of the main pulse from the residual burn-through foil plasma.

Workforce Development: Attract, develop, and retain tomorrow's technical workforce.

Score: Good
How does the project meet the appraisal criteria for Workforce Development?

Technical efforts were carried out by mid-career staff with the support of two post-docs recruited for this project (which is very good for an ER). This work improved the organizational, research and mentoring capabilities of the staff involved. However, both post-docs have left the Laboratory (to ELI in Hungary and to the NM Consortium). Project and Line Management should consider shifting their post-doc paradigm (consistent with LDRD guidance) to half-time support on well-funded programs (with additional program mentors) to enable broader training and greater career options for post-docs transitioning to staff.

Project efforts to expand fabrication capabilities into the additive manufacturing arena for their experimental targets was an excellent decision and will enable broader experimental options for future projects.

Strengths/Weaknesses:

Strengths:

- 2PP target development expands future target fabrication expertise and capabilities.
- Mid-career staff development achieved in program management, modeling of novel experiments and mentoring of post-docs.
- Two postdocs were recruited successfully for the effort which was quite impressive given the challenges of recruiting in this topical area in the U.S.

Weaknesses:

- The two post-docs recruited to work on this project now have left LANL, limiting the long-term impact for LANL's workforce.
- The publication output overall from the project (which is directly correlated with staff technical development) was rather low--two papers, few if any invited talks--so this effort, now in its fourth year, may have under-served the staff and postdocs who participated in this work. Again, this is likely a result of many factors, including a lull in national investment in inertial fusion energy, COVID, and the associated difficulties of attracting and retaining quality staff at Los Alamos during a pandemic.

Project Execution: Is the project on track and making progress towards the technical goals?

Score: Good

How does the project meet the appraisal criteria for Project Execution?

As discussed in the presentation, the team didn't get important OMEGA-EP shot time during the traditional three years of the project, so efforts focused on simulations and VLA experiments at CSU petawatt laser facility (the latter of which weren't directly applicable to fast ignition).

One concern is that the original idea of a double plasma mirror seemed to be dismissed as 'not a very practical idea' due to its 50% energy loss. Shouldn't this have been know during the proposal stage when Omega EP was identified as the experimental facility of choice?

In light of COVID challenges affecting experimental execution, the team adapted as well as could probably have been expected, though there are obviously regrets. Some sort of experimental contingency planning should have been part of the initial project execution plan, as the probabililty of obtaining LBS Omega EP shots is known to be quite low. Computational challenges were likely less profound since one can log into supercomputers remotely and perform calculations. Contributions on understanding cone-guided electron beam acceleration was very good, as was their work on super-ponderomotive electron acceleration during VLA, albeit not directly applicable to fast ignition.

The project would have had higher impact if, in hindsight and in light of these COVID challenges, the team had been able to pivot their planning and deliverables to find a path that would produce more publishable work from this effort. Two refereed articles (albeit one being a high profile article) seems low for a 3-year ER effort involving two postdocs whose primary mission is to publish aggressively for their career advancement. The team is encouraged to use the remaining campaign funding this year to bring this work to a satisfactory close and publish their work.

Strengths/Weaknesses:

Strengths:

- The team was able to adapt to the real-time challenges of not getting laser facility beam times and dealing with COVID restrictions.
- The project was able to perform complex simulations to computationally identify and demonstrate mitigation of problems previously encountered with cone-guided electron acceleration.
- The project eventually did obtain a post-project shot day on Omega EP, which speaks to the merits of the computation results they achieved over the beginning years of the project.

Weaknesses:

- The choice of Omega EP as the main experimental facility for this work, with its 3.5 ns pedestal pre-pulse in the GW power regime, may not have been a good choice. Weren't other lasers an option?
- The involvement of a senior scientist or program manager to help advise the project and enable more cross-communication and contingency planning would have been good.
- Metrics seemed lacking in the requirements/goals and results of what was obtained through the simulations. For example: What thickness foils are needed as the pre-pulse energy and temporal width change? Results showing the parametric dependence of the e-beam, as a function of cone and laser pre-pulse properties, would have been useful.

ADVICE TO TEAM

There is general concern by the committee that electron fast ignition ICF has not shown a viable path to inertial fusion because of the problems identified by P. Davies (Phys. Rev. E 2004) regarding resistive decay of return currents leading to a general inability to propagate an electron beam into the plasma. As admitted during the review, these fundamental challenges with electron fast ignition have not been resolved. This does not take away from the team's efforts and positive physics results, but it does suggest caution before more effort is invested in this approach for ICF ignition and as a viable HEDP energy driver.

A stong merit of this work is its potential to provide R&D solutions to problems in laser-target coupling that enable other programmatic applications beyond fast ignition. The Committee encourages the Project to focus their efforts on such programmatic applications in the future as this more likely may have long-term funding prospects at LANL. However, if the team does intend to pursue electron fast ignition, in addition to engaging LANL stakeholders (e.g., ICF Program Manager John Kline), the team is encouraged to participate in nascent Inertial Fusion Energy national planning efforts and engage the broader scientific community to find fruitful collaboration opportunities. Planning activities are ongoing with a DOE Fusion Energy Sciences Research Needs Workshop planned in Feb. 2022 and if a fast ignition ICF element is included, it would represent a possible follow-on funding source.

The lack of fast ignition experiments during the first three years of this ER was a major stumbling block that impeded advancement of this work. The Committee acknowledges that there is currently no representation on the shot allocation Council/Committees for LDRD sponsored shots on the major US laser user facilities, so LDRD is susceptible to the vagaries of the current members, all Program Managers with their own programmatic goals, to determine whether LDRD shots will be included in the Programmatic shot allocation, or supported for the extremely limited shots available through either the Laboratory Basic Science (on Omega EP) or Discovery Science (on NIF) allocations. Experimental participation without representation is difficult at best, and we implore the LDRD Office to seek ways to improve the current Omega/NIF shot competition process to be LDRD inclusive.

As noted during the review, collaborating with LLE scientists on K-alpha diagnostics for the upcoming June, 2022, cone-guided electron source experiments on Omega-EP might be a useful cross-laboratory effort to pursue.

We note that the first part of this project focused on experiments at CSU, although the presentation didn’t discuss these experiments in great detail. Putting that work in context, regarding its potential applications relevant to LANL strategic missions, may help future efforts in this area.

ADDITIONAL COMMENTS

Owing to the positive simulation predictions for the upcoming post-project Omega EP shot day in June, 2022, we believe the results from these experiments could have high scientific impact. Thus, if at all possible, we would like to recommend that the LDRD Office support the preparation, execution and post-shot analysis of these experimental shots.